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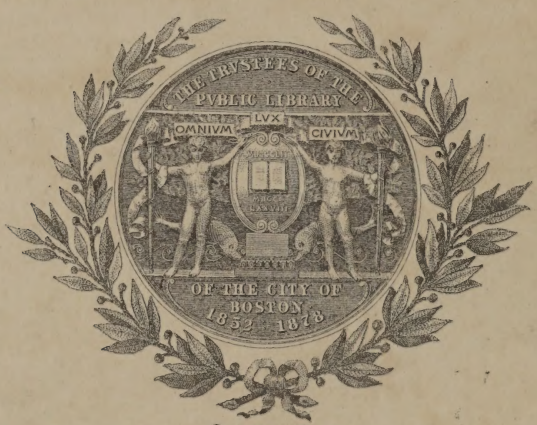

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NOTES ON THE INDIVIDUAL PSYCHOPHYSIOLOGY OF THE CRAYFISH.

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By GEORGE V. N. DEARBORN.

[From the Laboratory of Physiology in the Harvard Medical School.]

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CONTENTS.

	Page		Page
Introduction	404	Description of the Experiments	412
Incidental Observations on Crayfish Habits	405	Traction Strength	412
Method	405	Pinching Strength of the Chelæ	415
Eating and Taste	407	Re-turning Habits	418
Fear	407	Training	419
Touch	408	Reactions to Galvanism	420
Sight	409	Galvanotropism	422
Smell	410	Hypnosis	423
Hearing	410	Reaction-Time	425
Equilibrium	410	Inductive Results	426
Movements	410	Conclusion	433

INTRODUCTION.

EXPERIMENTS as to the different ways in which various individuals of *Cambarus affinis* Say do the same thing and as to the different methods employed by the same individual at different times, constitute the empirical basis of these notes. Of ulterior theoretic interest, there are included in the essay considerations as to the sense in which, if at all, the term *individuality* may be applied to the members of a genus as low in development as that herein examined. An article in a physiological journal is no place to discuss the philosophy of individuality, however biological the concept may be judged by some to be. It is enough here to denote one conception of the meaning of this term. We may say (avoiding all attempt at demarcation among the very lowest animal forms) that *a living organism is an individual in proportion to the relative constancy and strength of its own proper tendencies considered as manifestations of an inherent will.*

With this notion as a criterion, our theoretic inquiry will be devoted mainly toward a determination, closer perhaps than has been made, as to the degree in which correlations and constancies (which may

be said to represent "individuality" here) are present in the crayfish. Very much work has been done, of course (scientifically, only of late) on the general habits of different sorts of animals, and a certain part of this great mass of observations has been of value because at once systematic and exact. Less, much less, time has been devoted to a determination of the psychophysical habits of animals with the help of instruments of precision and exact description of small differences in their individual methods of doing things. Indeed, this sort of research is only just beginning to be conducted even on human subjects in our college laboratories and public schools. Such psychophysical studies have not only large future practical importance in their application to general education but they have also theoretic interest, as helping much toward an understanding of the relations of mind to body. To apply something of this type of method to animals whose individuality is simple enough to be somewhat definable, searching for constancy and correlation, is our present research. Temperament and mood and heredity and diathesis and other like important terms are still notions of extreme indefiniteness, which indefiniteness animal psychophysiology may perhaps help to decrease.

Incidental Observations on Crayfish Habits.

Method. — Specimens of *Cambarus* were chosen as subjects for this tentative experimental inquiry, for several reasons: — be their form and functions are simple but yet are developed su ly to exhibit a definable degree of individual variation; because hard crustacean covering in the winter season makes the app of instruments and apparatus relatively easy and at the same pro- tects them from injury by the necessary constant handling use they are easily obtained alive and readily kept in fresh w nd, being voracious eaters, are easily fed, thus maintaining th full physiologic vigor continuously; and lastly, because they are at home both in the water and out of it, thus allowing of more sorts of observation than else would be the case.

The experiments were made in the Physiological Laboratory of the Harvard Medical School chiefly during the last two months of 1899. Twenty-two adult specimens of crayfish were obtained, fifteen being females and seven males. They ranged in weight from 11.5 grams to 45 grams with an average of about 30 grams, while their lengths were from about 10 cm. to 17 cm. measuring from the end of

the abdomen to the tips of the extended chelæ. These individuals were chosen as the most vigorous and perfect of one hundred and fifty specimens. Their only defects to the eye were a frequent shortness of one or both antennæ and in a very few instances an asymmetry

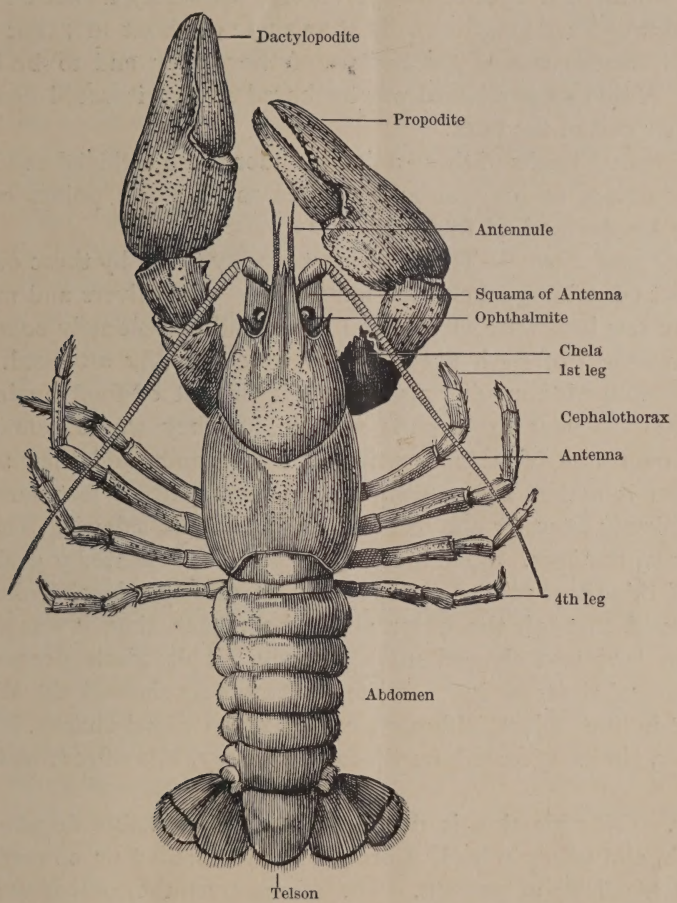

FIGURE 1.—*Astacus fluviatilis.* Tergal surface.
From Huxley: "The Crayfish."

in the size of their great claws. Each animal was at its receipt numbered on the back with white oil-paint, the females having the consecutive odd numbers up to twenty-nine and the males some of the intervening even numbers; thus each individual and its sex could be identified at a glance. They were kept in a convenient zinc tank

175 cm. long, 35 cm. wide, and 25 cm. deep, with an outlet-tube at about 15 cm. from the bottom of one end, while a stream of water from the city pipes entered at the other; when this water in the dead of winter became too cold, it was warmed by flowing through a double worm in a 25-litre copper boiler heated by a Bunsen flame. The tank was tilted longitudinally at an angle of about 10°, thus allowing a few centimetres of the bottom of the upper end to be free of water. A thin spruce board was anchored so that it would float near the upper end of the tank.

The general habits of these animals under these artificial conditions will not detain us long, although notes as to a few points may in passing be deemed of interest.

Eating and Taste. — The food most readily taken by these crayfish was meat containing much blood and juice. Frog livers and muscles and lean raw beef were often given them, and occasionally some artificial "worms" of fresh fibrin, which were greedily attacked. The third maxillipedes, serving also to press the bit of food against the jaws, seem to bear the organs of taste, for they would remain extended over a bit of meat sometimes a few seconds and then seize it and press it against the mouth, the foremost pair of feet serving to hold it firmly laterally and to tear it by pulling it sidewise back and forth from the jaws. One individual (No. XV) repeatedly grabbed a strip of thin sheet rubber cut to represent closely a leech, when this was waved through the water above her; each time it was pressed into the jaws and chewed upon actively. This whole process was done several times by her. None of the others showed the slightest interest in the object, although each had an equal chance. Many, however, similarly seized, on tip-toe, so to say, bits of red, worm-like fibrin.

Fear. — Horrification is developed to a remarkable degree in the crayfish, and offers in itself a problem as to instinct or co-ordination not easily solved at present. The phenomena themselves are well-known: Active stimulation or sometimes even the approach of an object such as would naturally give occasion for "fear" perhaps, often causes the animal to rise violently as far from the surface on which it rests as the extreme arrangement of chelæ, legs, and abdomen can bring about, all these being meanwhile in a state of extreme tonicity amounting often almost to a cramp of the muscles. Usually also in this condition the squamæ of the antennæ are adducted to their limit, a reaction observed constantly in some individuals but in

others apparently seldom or never. The interesting point of this whole phenomenon is that, assuming with Darwin that this process was developed as a protective instinct intended to frighten away enemies (a presumption not as yet superseded), in this case teleology has outdone itself, for a passionate or excitable individual often rises so vigorously and on limbs so rigid that he falls on his back in a way to put himself most completely into the power of any foe, being then comparatively helpless and exposed. It is interesting to note that this phenomenon may be occasioned sometimes as fully by stimuli received by the animal through the eyes only as by mechanical and often repeated irritation of the body directly.

Touch. — The sense of touch seems on the whole to be the sense of greatest value to the crayfish, so far as actions can indicate. By means of setæ arranged in little clumps in general all over the body, the animal's knowledge of mechanical disturbance near him is fairly complete, although the antennæ are doubtless the organs of touch in particular. These latter are carried usually, during forward progression, raised and somewhat adducted in directions to best strike against objects lying in the animal's path. They are by far the most perfectly mobile of the crayfish's organs, the tip of each possibly describing a hemisphere. When one of the animals is about to walk in a direction other than that in which his rostrum points, the antenna of that side, often even two seconds in advance, turns in the direction to be taken. This may show one of two things, — either that the intention of the animal is very slow in being carried out, or that the stimulus which determines this action comes from without the organism and causes this — the most sensitive organ — to move first. When one crayfish approaches another the antenna of the latter meets the former, touching him some place, usually on the antenna. Moisture is probably perceived by means of the antennæ; one of the animals which had been a rather long time out of the water, while walking over a large sheet of paper having on it here and there a wet spot, pushed his antenna on the paper before him and traversed the moistened places. The antenna seems rather sensitive to electric currents in the surrounding water; these, when strong, like other abnormal stimuli cause the organs to be laid closely along the back. The antennæ do not seem sensitive to a remarkable extent to heat. Oftentimes it is necessary to touch a crayfish in order to arouse him; vision seems sometimes asleep; this is especially noticeable apparently when the animal is in water.

Sight. — The importance of sight in the crayfish seems sometimes over estimated, for it probably is of less use to the animal in his normal life than touch. The eyes are very sensitive to the passing near them of large opaque bodies, and the withdrawal-reaction is often very marked in these cases. Sudden turning-on of a glow-lamp (16 candle-power) over their tank usually caused half of the animals or more to stir to a greater or a less extent; turning the light off likewise caused movements, but in a smaller number. Phototaxis was not studied under precise conditions, but would seem not to obtain in either mode; the crayfish appeared neither to seek nor to avoid a 32 candle-power lamp immersed in the water of their tank, although those near it seemed regularly to turn, if necessary, so as to "face" it. Withdrawal of the ophthalmites into their sockets occurs only on contact with some hard object — not from any light-stimulus of an ordinary sort. Crayfish seem to recognize their fellows at a distance of from 15 cm. to 20 cm., for the attitude of defence is taken sometimes when a comer is that distance away. So far as observed, no individual noticed certain rather conspicuous glass cylinders in the tank by sight, for when their course took them that way they ran awkwardly into them and then backed off.

Several individuals were blindfolded by bending around the cephalon a bit of sheet block tin, properly shaped, and held in place by a wire extending along the middle of the back and under the first abdominal somite; an orifice was left in front for the play of the antennæ and the antennules. Crayfish No. XII wore this closely-fitting helmet a day. During the first hour or so he repeatedly tried to remove it, using for this purpose the three forward pairs of legs and feet. His actions while blindfolded were seemingly homologous to man's under like condition, as regards getting about : — the gait was slower and more uncertain; when an antenna touched any object, the animal instantly stopped for five seconds or so and then advanced in a more or less changed direction. When blindfolded, No. VI was prone to revolve, the circle being each time somewhat enlarged. This same animal (the most sexually vigorous of all the males) on one occasion grabbed No. IV (another male) in obviously sexual embrace, the latter soon escaping. This occurrence, never observed by me under normal conditions of vision, indicates that crayfish p[illegible]sibly can distinguish, in part at least, the sex of their fellows by sight. This is a result rather unexpected, for the sexual differences, especially from in front, are slight. The tin helmet did not interfere with the ac-

tion of the organs of smell, by which sex perhaps in part may be discriminated.

Smell. — On the sense of smell no adequate experimentation was attempted; a few tests, simply, were made on the sex individuals numbered from II to VII. Three odors only were employed, and not knowing what particular smells were disagreeable to the crustacean, those were naturally selected to which humanity usually objects. Asafœtida, ammonium valerianate, and long-decayed fibrin infusion in combination make a quite resistless olfactory stimulus. In all possible forms, singly and in combination, these were presented to the six subjects both in water and out of it, but it was at no time suggested by any act on their part that these odors were perceived by them. This fact is of course no proof that the sensation of smell was not experienced, but it is at least presumptive evidence that nothing in the nature of unpleasantness or pleasantness came within the sensorium of the animals, for these are usually correlated with appropriate movements.

Hearing. — No signs of a sense of hearing were at any time observed, although the range of auditory stimuli applied was large. Sudden pressures in the water, however, seemed plainly to be felt, and for these perhaps the crayfish otoliths are tuned; (this question is still in doubt even in the case of man).

Equilibrium. — Simple experiments were performed on three individuals (IV, XV, and XXV), to determine if they possessed organs concerned with bodily balance which might, as in man, be disturbed by rotation about a vertical line in the middle of the body. An earthenware two-kilo bowl was filled with water and the crayfish placed within it. A forceful stream of water was then applied to one rim, and the whole rotated at the speed desired. No. IV was rotated once a second for five minutes but showed no sign of vertigo or ataxia, and immediately afterwards ambled away quite as usual. Nos. XV and XXV were rotated similarly for six minutes with like negative results. This is a situation in which one would suppose they might at times find themselves in rapid brooks, and the result is suggestive. The compensatory movements of the ophthalmites were not studied.

Movement. — The gait was carefully watched on two different days. Without a series of kinetoscopic photographs a leg-order so complex is no easy problem to define, and individual variations are yet more difficult of record. It was learned, however, from the two or three

days of study that no precise formula or rhythmical co-ordination was constant either in the crayfish as an average, specific animal or in the individual from day to day or hour to hour. There seems in general to be a distinct tendency for the four pairs of legs to be moved forward successively from before backwards, the two legs of a pair more often moving together, yet often not. The foremost pair are limbs rather highly differentiated as prehensile organs, as toilet implements, and as arms bearing fingers much more nimble than the clumsy chelæ; on this account perhaps, in part, the first pair often fails to keep the "step." The second pair are used in general similarly, but much less often for prehension and then with far less skill. The third pair seem to be for the purpose of walking chiefly; on them most of the weight is borne at times; this pair are most often in unison of movement with the second pair. The fourth, or hindermost, legs are more or less like stiffened, although jointed, props by which the animal pushes himself, to some extent, along, and holds his place on inclines or against the current. These are obviously used quite as the convenience of the moment dictates, and are therefore more often out of the typical rhythm than any of the other pairs. In some cases the chelæ are used as legs in walking, oftener yet in standing, and in horrification, already noted, they serve to support and give stability to the raised body. The crayfish walks in every direction, most often forwards, but readily also sidewise, obliquely, or backwards.

One of the most noteworthy facts, apparently, in the motivity of the crayfish is the distinction which seems to obtain between the muscles of the cephalothorax and those of the abdomen as regards their innervation and relation to the proper will of the animal. While each of the limbs of the cephalothorax, possibly excepting the ophthalmites, may be said in a sense to be under control of the animal's will, what correspond to voluntary muscles in higher forms, the contractile organs of the abdomen, the large flexor in particular, seem to be almost "involuntary," acting reflexly and ordinarily from some sort of shock to the neural mechanism in some part of the body. The series of large muscular bundles which constitute this flexor abdominis work always together more or less and their simultaneous sudden contraction causes the crayfish to dart backwards in the act of swimming. This under normal conditions the animal appears never to do unless "frightened" or shocked; it may then make an indefinite number of graceful swimming jumps. That this

compound muscle may, however, at times come partially under voluntary control, will be shown later on. In general this distinction is sufficiently striking, indicating perhaps that the abdomen was developed by natural selection as a protective means of escape from dangerous foes, but that it has not as yet come under ordinary individual control. On the other hand the extensor abdominis muscle is much better within the influence of the animal's choice or immediate needs irrespective of stimulation from without, and is often of use to the individual, as in re-turning from the helpless supine position.

The accuracy with which the crayfish can direct and contract its chelæ and antennæ was a subject of experimentation until abandoned for lack of time and patience. This was because it is very difficult to induce one of these animals to make a movement which may properly be called voluntary, such as a deliberate reaching after a small object under measurable conditions. This difficulty is indeed in general an index of the psychophysical development of this species; the neural simplicity probably does not allow any action purely deliberate. When the animal is highly excited it seems as if spontaneity merged with reflex movements more than usual. It appears that when such movements with the chelæ can be induced, their accuracy is considerable, although limited by the rigidity of the hinge-joints on which the chelæ are mostly moved. The antennæ may obviously be directed with extreme nicety to any objective point. As to the quickness of these movements in relation with accuracy it is difficult to make reliable statements, the variation being so extremely large. Sometimes the swiftness with which the animal raises his claws in defence seems extraordinary and often the swimming-jump backwards follows the stimulus too quickly for ocular estimate, accuracy then being wholly disregarded. This whole field of the accuracy and speed of bodily movements in various genera up and down the animal kingdom, appears to the writer a most fertile one, especially the *development of voluntary movements* both in the individual animal and the child and in the phylogenic unfolding of every empirical grade of life.

Description of the Experiments.

Traction strength. — The first series of experiments on the various crayfish which will be described related to their respective powers of traction. For this purpose twenty individuals were employed. Each was tested on three days, the second day two days after the first and

the third day nine days after the second. The following simple apparatus was used: A brass-wire spring having such strength that a weight of 100 grams caused an elongation of about 20 cm. was suspended from a rigid clamp about 50 cm. above a table. From the lower end of this spring a strong linen thread was passed around a large, easily-turning brass pulley and thence horizontally over a sheet of white paper to a coarse, tightly-stretched towel tacked to the table, where the thread ended in a small silk-covered wire loop of considerable size. A scale made by noting the extension of the spring when different weights were attached to the thread was then marked on the sheet of paper. The wire loop was passed around the abdomen of the crayfish at the junction between the fourth and fifth somites so as to draw from beneath, and the animal was set upon the wet towel and gently tapped with a glass rod. This invariably caused him to walk forward over the surface before him, drawing on the gauged spring. The point at which the index on the thread over the scale indicated the maximum force exerted was marked with a pen. The average time consumed by the crayfish in reaching this maximum point was from one to three minutes; fatigue then rapidly ensued. A second trial was always given immediately and sometimes a third, but it is noteworthy that the record of the second attempt was always behind that of the first by an average perhaps of fifteen per cent. This seems a good test of the general strength of the various animals, for it involves the exercise of nearly all the muscles of the larger appendages, chiefly of the ambulatory legs of course but also in a less degree of those of the chelæ and abdomen as well. Any record made by flexion of the abdomen, which occasionally occurred, was disregarded.

The accompanying Table I gives in detail the numbers derived from these tests of crustacean traction-strength. In it, the first column contains the numbers of the individual crayfish; the second their respective weights in grams; the third, fourth, and fifth columns the records of strength in grams on the three respective days of the experiments; the sixth column consists of the averages of the three performances; and the seventh the traction strength per gram of body-weight, thus reducing the results to an absolute standard, for direct comparison. The large individual average variation of these records may be seen at a glance across the columns; it is large however only from our, that is the anthropomorphic, view-point. This is a characteristic of the actions of these low forms of life, interesting

TABLE I.

Individual Numbers.	Weight of Crayfish in Grams.	Weight Pulled.			Averages. Grams.	Traction-Power per Gram of Body Weight.
		First Day. Grams.	Second Day. Grams.	Third Day. Grams.		
I	11.5	38.0	32.5	34.0	35.0	3.5
II	35.	45.0	57.0	55.0	52.0	1.5
III	45.	75.0	80.0	82.0	79.0	1.7
IV	25.	67.5	63.0	66.0	65.5	2.2
V	33.	64.5	62.5	68.5	65.0	1.9
VI	35.	66.0	67.5	49.0*	67.0	1.9
VII	44.	98.0	102.0	100.0	100.0	2.3
VIII	28.	70.0	81.5	88.0	79.0	2.8
IX	32.	48.5	74.0	53.5	59.0	1.8
X	26.	67.5	72.5	63.0	68.0	2.5
XI	32.	64.0	99.5	89.0	84.0	2.6
XII	22.	48.0	58.0	49.0	52.0	2.4
XIII	28.	42.0	44.0	66.0	51.0	1.8
XIV	18.	44.5	58.0	59.0	57.0	3.1
XV	37.	61.0	75.5	84.0	74.0	2.0
XIX	33.	68.5	71.5	49.0	63.0	1.9
XXI	27.	72.5	78.5	62.0	71.0	2.6
XXIII	29.	58.0	64.0	60.0	61.0	2.1
XXV	29.	73.5	83.0	79.0	79.0	2.7
XXVII	19.	45.0	73.0	62.5	60.0	3.1

* One leg broken.

Average, 2.3.

to compare with the average variation of similar performances by human subjects. It is sufficient here if its relative greatness be noted. The results of the experiments will be somewhat discussed later on, when all of them may be reviewed together, and in relation to our main question.

Chelæ's pinching-strength. — The next series of observations on the crayfish with instruments of precision recorded the pinching-force of their chelæ or "claws," — in more technical terms the strength of the adductor muscle which draws the dactylopodite toward the propodite. To measure this force a myo-dynamometer describable as follows, was constructed, suited to this animal, and crabs, perhaps, alone: A piece of brass spring-wire of about $\frac{1}{16}$ inch gauge was wound twice about a small steel rod, and one end cut 20 cm., the other about 35 cm. long. The upper of these, the index arm, was bent into a depression near the double coil, thence extending straight, so that it formed with the lower portion an angle of about 40°, the two wires at the place of the depression (intended to define the place of application of the chela) being 1 cm. apart. The last 15 cm. of the lower arm was bent in the form of an arc over which the index arm was to play; on this arc was fastened a metallic scale readable to the nearest 25 grams up to 2,000 grams, and made empirically by suspending scale-weights at the notch where the chela was to pinch. Strips of "tin" were rigidly fixed to the lower arm for purposes of convenient clamping in position on the table's edge; a glass tube, lessening friction, extending along parallel to the scale to confine the index-arm and prevent its bending away, completed this simple dynamometer.

In making a test, the crayfish was taken from the tank and held near the instrument in such a position that he would seize, usually with only too great readiness, the arms of the instrument in his right chela at the notch made for the purpose. The animal was then stimulated to his most active effort by tapping with a rod about the cephalon, gently, and each subject alike. The tips of the claws of the crayfish are slightly bent inward, and it was always just within this beak that the arms of the dynamometer were taken, the pressures registered thus being the smallest exerted by any part of the forceps, these being progressively greater nearer to the hinge. After the right chela had been made to grip the instrument twice, the left was applied in a similar way, the position of each in relation to the dynamometer being constant in all respects. Indeed, in all the sets of experiments

care was used to have no partiality to any individual in any regard, thus only allowing of comparable results being obtained.

The accompanying Table II gives the numerical results of this set of experiments, although in the rather anomalous terms of body-weights. It was not convenient to mutilate each animal either dead or alive for the purpose of weighing its adductor muscles. But weighing was the only way to reduce their strength to the "absolute standard." On the other hand, the conditions of the dynamometer made it impossible to use the other common method of measuring muscular work, namely, in gram-centimetres, as there was no lifting of the maximum "weight." Of several chela muscles weighed that of the right forceps of No. V may therefore be taken as an example, although apparently a muscle stronger than the average. Its work was calculated according to the absolute standard. The mechanism is, in fine, a broad bipenniform muscle acting on a lever of the third class by means of a powerful bony tendon, thereby, as already noted, adducting the dactylopodite against the propodite. The lever acts on any resistance placed, as here, in the beak at the tip of the claw at a disadvantage in force of about nine and one half times, making this up, of course, in speed and latitude of movement. The indicated pinching-force at the tip was 1,600 grams, thus showing that the actual pull on the muscle's tendon was 15,200 grams, or 15.2 kilos. The muscle in question weighed 0.7 gram, and from this and other data it was readily calculated that the absolute strength of this particular muscle was approximately 7.6 kilos per centimetre of cross-section. This is a number somewhat less than that usually accepted for the muscular strength of man, who has the highest proportional strength. The amount by which, in general, the strength of the left forceps was smaller than the right, is very likely a rough index of the fatigue of the individual. There was no indication of any unequal usage of the two chelæ, the animal being strictly, both in form and function, in theory bilaterally symmetrical; accidents, however, make defective individuals common. In several cases, not reported in the foregoing table, the force exerted by one chela was measured while the other also was gripping an object, the animal's attention thus being divided. Under this circumstance it was found that the strength then exhibited by one chela varied between 76 and 21 per cent of that exerted when only one was in use, the average being approximately one third; this curious fact the simultaneous use of two dynamometers might have explained. The theoretic

TABLE II

Individual Numbers.	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XV	XIX	XXI	XXIII	XXV	XXVII
Weights in Grams.	35.	45.	25.	33.	35.	44.	28.	32.	26.	32.	22.	28.	37.	33.	27.	29.	29.	19.
Right Chela. Grams.	1450	1600	1500	1600	1300	1550	* 400	1100	†	1550	1200	600	600	1425	1100	700	650	300
Left Chela. Grams.	900	1000	*	1100		1200	1400	100	350	1300	1000	675	700	1000	1250	250	* 350	
Right Grip in Body-wts.	41.4	35.5	60.0	48.4	37.1	35.2		34.3		48.4	54.5	21.4	16.2	43.1	40.7	24.1	22.4	15.7
Left Grip in Body-wts.	25.7	22.2		33.5		27.2	50.0	3.1	13.4	40.6	45.4	24.1	18.9	30.3	46.3	8.6		

Right chela's mean, 35.3.
Left chela's mean, 25.5

* Chela secondary and too small.

† Chela broken.

result from this set of experiments which particularly interests us here is the large individual variation, larger still than that of the traction tests just described.

Re-turning habits. — The next series of experiments involves in the subject other elements than mere physical strength, namely, individual habit and a general sort of knack. It was noticed that the individual crayfish differed considerably in their faculty of righting themselves or re-turning when they had been placed on their backs on a smooth plane level surface in water. Without assistance, there are two modes by which one of these animals may re-turn when on a sheet of glass in water of sufficient depth. The former of these, the more common method, is that which a man, for example, would employ, namely, raising himself on his limbs in a way to fall over by force of gravity; the latter, quicker and more certain by far, is by means of a quick contraction of the flexor abdominis muscle, causing a quick swimming-movement backward, which action invariably lands the animal right-side-up. On the other hand, nearly half of the twenty animals employed in this set of experiments could not within five minutes of almost constant endeavor re-turn by either or any means.

To study the nature of the various individuals' habits in this particular and their constancy, whatever they were, accurate account was kept of the performance of each on three different days, both as to the ultimate outcome of each attempt to re-turn (five minutes being the limit of endeavor) and as to the time required. A very large porcelain evaporating-dish containing water at 23° and 10 cm. deep was employed for the experiments. A stop-watch accurately gave the time in each case. The crayfish was gently placed on its back in the middle of the bottom of the dish, whereupon it invariably began struggles more or less well directed toward re-turning. Five trials of each animal's faculty were made in succession on each of the three days, unless its complete inability to turn over was obvious after one or two five-minute struggles, when sometimes the rest of the five performances were omitted, for it had been learned empirically that an individual which could not re-turn within five minutes could not do so at all, at least not within the limits of a convenient experimental period.

The completeness of the numerical results of these experiments was lessened by the unexplained death of some of the subjects between the second and the third trial-days, which were some weeks

apart. The performances of the two first days were as follows. Three of the twenty crayfish invariably re-turned by proper balancing in periods ranging between 1.2 seconds and 49 seconds, the average being about 10 seconds; seven individuals failed to re-turn within the allotted time; one invariably re-turned by the flexion method; and the remaining nine subjects sometimes failed and sometimes employed successfully one or the other of the two methods. On the third trial-day there were eleven individuals tested, and they acted in no way generally unlike the twenty of the two previous days. Here, then, will be observed a certain degree of individual habit in a complex psychophysical process, but, perhaps more noticeable than this is its opposite, the absence of constancy. The inability to re-turn was more common than any successful method, and although the conditions all the while did not vary, even this inability was inconstant.

Training. — It was next experimented whether *training* would change a re-turning habit employed by any individual or improve the faculty in those which in these last experiments could not re-turn by any method. For this purpose, advantage was taken of the fact that a tap on the sternal surface of the abdomen, especially on the first somite, or pressure on the telson, causes an immediate flexion of the abdomen and, as already explained, a consequent quick and certain re-turning. By inducing this process a number of times in succession, it was thought possibly some sort of disposition might be impressed upon the neuromuscular mechanism which would make it easier for the animal to perform the action for himself when need presented.

Five individuals were accordingly so treated and observed, to learn if such lowly animals could be trained by the method probably most productive in their grade of development. Of these, No. III, in her test performances, on the first day had re-turned by abdominal flexion once and failed to re-turn the other four times; on the second day, failed the first time and was then used for another experiment for half an hour (being often galvanized), then tried again whereupon she re-turned by flexion five times in quick succession; on the third day, she had re-turned by balancing five times successively. She was then, for her training, induced to flex her abdomen when lying prone forty times in quick succession, each time re-turning quickly. Yet on trial she failed entirely to get over within five minutes despite strenuous efforts to that end. No. IV, which had re-turned on the two days he was tested by flexion each of the five times quickly, at the training test re-turned by flexion four times speedily and then by balancing

thirty times in succession in periods ranging between 9.7 seconds and 103.7 seconds. This animal had skill at re-turning above the rest, once almost succeeding in slowly overturning longitudinally by raising himself on the tightly-flexed abdomen. No. VII in the three previous trial-days had invariably failed at re-turning. No improvement was manifest after a training of forty flexion-re-turnings with a two-hour interval between the first and second twenties. The next day she failed on trial and five flexions had no effect. No. VIII, which had re-turned in his three days of trials either by flexion or, less often, by balancing, righted himself by balancing ninety times in quick succession, the longest period required being 13.0 seconds with an average of perhaps 5.0 seconds. The times started short, became gradually longer, then shortened slightly with an increased variation until the experiments were stopped. This animal invariably turned over the same side down even against a considerable opposing inclination of the surface, the reason for this being perhaps that the chela of that side was apparently secondary and still slightly smaller than the other, a habit thus having been acquired. Lastly, No. XXV (which had always re-turned by balancing), was stimulated to re-turning by flexion fifty times in succession (about the reasonable limit), yet showed absolutely no tendency to re-turn by flexion of her own initiative immediately afterward.

Reactions to galvanism.— Knowledge as to the relative sensitivity of the different individual crayfish to galvanic electricity was the object of the series of simple experiments next to be described. As apparatus there was employed a water-filled glass dish 24 cm. in diameter and 7 cm. deep and cylindrical in shape. About the rim of this vessel from top to bottom were fixed two tin-foil electrodes opposite each other and each about 16 cm. long. Connected with these electrodes were the poles of a battery of four Daniell cells arranged in series, and connected in such a way with a key that either one, two, three, or four cells (each slightly over a volt) could be instantly thrown into the circuit, which last contained in addition a Du Bois-Reymond key, and a Pohl commutator for reversing the current. Thus the current which was driven through the water in the glass dish could be instantaneously made or broken, reversed, or varied in four degrees of strength between one and four volts tension. Strips of glass on edge extended between the extremities of the electrodes in the dish thus confining the crayfish to a channel about 14 cm. wide with the electrodes at its ends 24 cm. apart.

The same twenty individuals which were studied as to their traction-strengths were used as subjects in this set of observations. The current from one Daniell cell through the amount of water here present appears to be about a threshold stimulus to movement for the "average crayfish." That from four cells produces a muscular tonicity which prevents the noting of its specific effects, while even with a three-cells current the reactions are so strong that the uniformity in different individuals is extreme, these reactions being in general spasmodic flexions of the jointed limbs and abdomen. We shall relate the details of the various reactions to the one-cell current and to the current of double that strength, only. The crayfish during these reactions was always head-on to the electrical flow, that is, with the rostrum pointing to the anode. The movements noted are those which occurred immediately on making the circuit with the Du Bois-Reymond key.

On making the one-cell current, crayfish I reacted by adduction of the exopodite of the telson and by no other visible movement; II, vibration of the filaments of the first and second maxillipedes and flexion of the third maxillipede; III, no visible reaction; IV, flexion of third maxillipede; V, vibrations and flexion of maxillipedes; VI, flexion of maxillipedes and sometimes closing of forceps of the right or of the left front leg; VII, slight adduction of right antenna; VIII, no visible reaction; IX, X, XI, XII, ditto; XIII, vibration of antennæ; XIV, no visible reaction; XV, marked flexion of third maxillipedes and adduction of antennules; XIX, vibration of antennules; XXI, adduction and lowering of antennules; break caused opening of forceps of front leg; XXIII, slight general forward movement; XXV, no visible reaction at make; break caused relaxation of forceps of front legs; XXVII, no visible movement at make; break caused general slight movements.

The make of the two-cells current caused in I the same reaction as before plus slight rotation of right chela; II, same as before plus slight flexion of chelæ and adduction of antennæ; III, first time, slight forward starting of whole body, afterwards slight flexion of right chela; IV, slight extension of left chela, flexion of right chela, closing of forceps of same, adduction of antennæ; V, first time, general starting; afterwards, closing of forceps of front legs and slight flexion of chelæ; later on, violent flexion of abdomen; VI, same as before save that "closing of the forceps of the right or left front leg" was now constant; VII, same as before plus general movement of body;

VIII, flexion of abdomen, and of chelæ and adduction of antennules; IX, flexion of right chela; X, flexion of chelæ, closing of forceps, flexion of the third maxillipedes; at break, relaxation of forceps of front leg; XI, slight flexion of right chela and flexion of abdomen; XII, slight flexion of chelæ; XIII, no visible constant reaction; at break, relaxation of limbs; XIV, flexion of chelæ and adduction of exopodites of the telson; XV, flexion of maxillipedes and of right chela; extreme abduction of left antenna, adduction of antennules; XIX, adduction of right antenna, flexion of chelæ; XXI, slight flexion right chela, vibration of antennules; XXIII, general slight flexion of limbs; XXV, vibration of the third maxillipedes; XXVII, slow general flexion of limbs. One cell occasioned flexion of the abdomen in none of the subjects; two cells in three of them; three cells in seven of them; and four cells in eleven of them. Perhaps the wide application of this method would reveal interesting relations between stimulus and reaction.

Galvanotropism. — The next series of experimental observations related to individual variations in galvanotropism. The same twenty individual crayfish that were used in the experiments just described were studied in this regard, each of them being observed twice at least on two different days. The apparatus used was likewise that of the last set of experiments, the Pohl commutator being here of essential importance for instantly changing the anode from one side of the dish to the other. The individual reactions in this case will not be detailed because every one of the twenty crayfish invariably went to the anode even with a two-cells current if given time enough. Very often he reacted more quickly with a four-cells current, although this in some cases caused tonic contractions which impeded movement. The individual variations were of course in the two directions of required time and method, but these would be very difficult to describe succinctly; the essential point for us will be noted later on. The hibernation instinct, impelling the crayfish to remain in dark corners (in these tests especially near the cathodal electrode), seemed to oppose the galvanotropic tendency somewhat. The arrival at the anode was usually promptest when the abdominal end pointed in that direction when the current was made, the animal then jumping or swimming thither by abdominal flexion. The arrival was slower when the crayfish was head-on to the current, in which case he scrambled to the anode or walked more or less deliberately. It was least rapid when he was in a position transverse to the current lines, in which

case general movements were continued until the animal became turned partly about, when the anode-seeking became much more certain. Rarely only would the crayfish sidle to the anode directly. The sensitivity of the organism to galvanism seems to lessen after a few minutes, both the reactive movements in general and the galvanotropism decreasing. That the electricity acts as a decided irritant is shown by the frequency with which the crayfish stroked their most sensitive appendages, as for example the antennæ and maxillipedes and ophthalmites with their fore "feet" and their chelæ. Oftentimes the current appears to act as a true *motive* for seeking of the anodal pole, for an animal occasionally would go to the anode a number of seconds after the circuit had been broken, indicating possibly some more or less persistent change in the cells of some part of the neuromuscular mechanism. No. XII went back and forth to the anode, as the current was alternated, in periods as short as three seconds; but most often the reaction-time was considerably longer, requiring often several minutes, during which the continual uneasiness of the organism would gradually resolve itself into slow progress toward the anode. If the crayfish were insensitive and settled down in a corner sometimes shocks frequently alternated were necessary to arouse them. The vessel employed was obviously not the best devisable for a study of the phenomenon as such, nor was it so intended, comparison of individual reactions being here our sole aim. No. XXV tried persistently to climb out of the glass dish whenever the current was on, although she was a small animal and without record of unusual sensitivity.

Hypnosis. — As a phenomenon having a still larger mental element, perchance, in its production, the "so-called hypnosis" was next employed. Eighteen individuals — those which used the dynamometer — were compared. Whatever be its nature and explanation, the condition referred to is simple enough practically, it being merely a greater or less permanency of position obtained whenever an animal of certain psychophysical simplicity is forcibly held in that position for a time. The crayfish in general readily comes under the influence, although with very various readiness, as will be seen. Each animal was hypnotized several times, and data as regards required time, duration of hypnosis, mode of awakening, etc., carefully kept, for both of the factors first-named enter the problem of comparing the susceptibilities of various individuals to the hypnotizing force. The method employed was simple enough, the animal merely being strongly held

with both hands in the chosen position in a way to prevent all possible external movements, until he no longer struggled. Apparently the only condition as regards posture is that it should be stable in relation with gravity; otherwise the shock of falling wakened the subject when the hands of the experimenter were removed.

The times required for hypnotizing the various crayfish varied largely, and the individuals seemed to have no constancy of their own. The period of impression was rarely under a minute, one case however (XIII, third time), requiring only 31 seconds (lasting about ten minutes), while in another subject (X, second time), seven minutes failed to reduce the spontaneity in the least so far as observable. Between these extremes of time every period, so to say, was recorded, the majority being about two minutes. A 16 candle-power glow-lamp held close before the subject's eyes seemed sometimes to shorten the time required. The period during which the animal remained in the imposed posture seemed to be proportionate to the time the will-subduing force was active, except for very brief periods of impression which were too short for a fair effect to be produced. The actual periods of persistence also varied largely in these experiments, the longest observed being about 27 minutes (XXV, second trial), although the laboratory conditions were not of the best at the time for this particular purpose, there being somewhat too much noise, jarring, and variation of light. Susceptibility seems to increase distinctly with repetition of the impression on the average, but this is very erratic. Crayfish X, for example, required at his first experience two minutes for an effect lasting eleven minutes, but at the next trial seven minutes failed to impress him in the least, while at the sixth attempt five minutes of the influence similarly had no effect; a month or so later at the second trial an impression of ten seconds endured twenty-eight minutes. The hypnosis comes to a close usually with suddenness, sometimes with even a general leap when the animal has been in the head-down position. Any sort of sensory stimulation seems able to bring the condition to an end, probably excepting sound stimuli, which were never at any time successfully employed in this research. When held in either the sternal or the tergal position the effect is produced as readily as in any other perhaps, although it is less easy to produce unusual muscular and joint strains under these conditions. Under water hypnosis can also be accomplished in the case of the crayfish, but only with far greater difficulty. VI required an impression of six minutes to stay ten seconds in water, when on his back, whereas

after seven seconds' influence when out of water he stayed placed 15.5 minutes. That one may compare the actions of a crayfish hypnotized on its back and those of one merely laid on its back, the following is given: No. III, hypnotized by restraint of legs and extension of chelæ and abdomen along the table for 1.5 minutes, remained perfectly still externally for 17 minutes. Similarly placed but unhypnotized, she made lively general movements for three minutes, lay still 15 seconds, moved 45 seconds, lay still ten seconds, etc., thus continuing for some time; at the end of seven minutes she lay still a longer period, and then moved seven minutes more — when she was put back into the tank. With the production of this state unusual posture would seem to have nothing to do, for this same crayfish was suspended by the distal end of her abdomen for ten minutes in air without any sign of hypnotization, although a relatively susceptible subject.

Reaction-time. — The last formal set of experiments which we shall at this time describe were concerned with the crayfish's reaction-time, so far as he has any. Reaction-time is a psychophysical determination which in the human individual has no little importance aside from its historical interest, for it is in a degree apparently an index of the vigor of a will or personality.

The apparatus constructed in this case was as follows: No Hipp chronoscope being at hand, a rough substitute was arranged which proved to be quite sufficient for the purpose intended. Three electric pens were arranged to write on a rotating smoked drum each precisely above the other, and each was supplied by a separate storage battery of its own, the lines traced being about 3 mm. apart. The uppermost pen made a vertical mark when the signal-stimulus was applied to the crayfish, the middle pen marked the instant of the animal's reaction (closing of the forceps of one chela), and the lowest pen recorded time-intervals by means of an Ewald electrical metronome placed in the circuit. Fifths of a second were at first employed, but were afterwards changed to halves. The flexible poles of the signal circuit ended in an instrument especially constructed of sheet copper, rubber, and wood so that pressure on the point of the key bent at right angles to its handle instantly completed the current. The reaction-key was made of like materials, the poles ending in pieces of hard rubber, which being pinched together by the reactor, instantly made the current and determined the record of the time intervening since the stimulus was felt.

The method of experimentation was simply thus: A crayfish, having been blindfolded by the tin helmet already described, was placed in a rubber-lined brass clamp fashioned so as to hold him firmly but comfortably about the whole length of the cephalothorax, and at such a height above the table that his legs and chelæ could conveniently touch it. The reaction-key was then placed within either one of his usually open chelæ, and while the animal was in the ordinary state of reactive excitement or "anger" or whatever the reader may please best to think it, he was vigorously tapped with the end of the stimulation-key, most often on some part of the chela employed for reaction or else on the antennæ or elsewhere about the head. The location of the stimulation seemed to make no difference. The interval between the two marks made on the smoked paper could then be read by comparison with the accompanying time-intervals, this being the "reaction-time" desired.

Ten individuals were studied in this portion of the research, many reactions being taken from each of them. The mean value for each subject was as follows: —

II	0.20 sec.	VIII	0.23 sec.
IV	0.55 "	XI	0.30 "
V	0.25 "	XII	0.65 "
VI	0.35 "	XXI	0 33 "
VII	0.43 "	XXV	0.30 "

The mean variation, which was instructively large, will be considered later when comparing the results in general. The writer regrets that the reaction-times of more of the crayfish at first possessed are not available.

Inductive Results.

Having now stated our problem and reported the greater part of the experiments performed toward its solution, we must next see what these experiments mean in that direction. Is there in an animal of an order as low as that of the crayfish anything, discoverable empirically, comparable to the psychophysical individuality of man? In such a direction lies our present inquiry.

In our set of tests of crustacean traction-strength, the most purely somatic of the functions, not strictly automatic, were investigated, for walking is in general controlled by a minimum of voluntary attention, and in these experiments the subjects only walked against resistance. Brief perusal of the table in which the numerical results of this set

of experiments are set forth shows how variable and vacillating were the performances of many of the crayfish in even this direction. No. XI, for example, on one day drew 64 grams as his maximum, and two days later 99.5 grams; XXVII, 45 grams, and at the later trial 73 grams. The smallest crayfish of the lot, No. I, drew an average of 3.5 times her own weight; while No. IX drew only 1.8 times her weight. With a mean strength of 2.3 times the body-weight, the mean variation in one case was over 50 per cent. Certain individual variations in conduct while being tested may in addition be briefly noted. Most of the subjects walked forward directly at their ordinary gait at first, but, with the increasing pressure to overcome, more slowly until, near the limit, each centimetre of advance was gained only with obviously much effort and by the putting-forward of a single leg. A few individuals acted much as does a balky horse, doubling up and refusing to proceed until left alone for some time. Others walked persistently in a curve toward one or the other edges of the table. The maximum endeavor was clearly enough defined in most cases or even in all, — there being a point reached beyond which the animal by any inducible pushing on his legs could not further advance.

In the set of experiments next described, those on the pinching-strength of the chelate forceps, there seems to be a somewhat larger "psychical" element involved than in the foregoing experiments. Here the individual showing the greatest strength gripped 60 times his body's weight, while the weakest was, as may be said, perhaps one fourth as strong, exerting a pressure equal to only 15.7 times his weight, and this was the crayfish which of all those then living made the best record at traction: 34 per cent above the mean in that test. Of two with the strongest chelæ, one was just below, and the other just above, the mean traction power. In case of the left chela, the largest mean variation recorded was about 100 per cent. In general, those which were strongest in their right chelæ made the lowest records at traction, while in case of the left chela, the correlation is more perfect, occurring, as did its tests, under a degree of fatigue. On the whole, as regards the strengths of these animals' great forceps, the results show a lack of co-ordinated constancy which would by no means be foreseen in a number of healthy crayfish living lives so nearly alike. The variation found was larger even than in the traction inquiry, and showed a much larger influence of fatigue. A not inconsiderable factor of "will-power" seemed usually present.

In the experiments on the faculty of re-turning when placed on the back in water, the crayfishes demonstrate well the fickleness or even the absence of a habit or knack which one might in advance suppose would be almost as fixed as a "reflex." In these experiments there was presented to the subject for solution a dilemma disagreeable only in so far as any unusual position is disagreeable to any animal from the disturbances which tend to arise in the visceral mechanics, from unusual strains, sensations, etc., but still so unnatural as to be in normal conditions invariably strongly opposed by immediate and almost continual attempts at re-turning to a position more habitual. This falling-over happens often enough to the animal in his natural habitat, for he is something of a climber and of necessity often falls, usually, however, among plants or rocks or roots or what-not on which he can at once lay hold and thereby right himself. When, as here, all environmental helps are lacking, there is an opportunity for an exercise of individual method. Of the twenty crayfish employed on the two different days of the experiments in question, only one re-turned each of the ten possible times by the quickest but most unnatural method, the quick flexion of the abdomen; only three turned over, within the five minutes allowed, by balancing; seven could not turn over by any method; while nine, almost half of all the individuals, sometimes turned one way, sometimes another, and sometimes not at all. This relatively large proportion of helpless individuals bears no relation to somatic strength or vigor, for those which could not re-turn were at traction and gripping at least average performers. This 45 per cent of subjects which were inconstant in method and result is what chiefly interests us theoretically — those which could not re-turn or else returned one way or another, — for the conditions meanwhile, so far as external to the animal, remained constant, and the variation must have been characteristic of their nature.

This habit-variation is all the more interesting because of the distinction already noted which seems to obtain between the movements of the appendages of the cephalothorax and the action of the large flexor of the abdomen. This is best seen in the conditions under which alone a crayfish swims, namely, never when tranquilly about his business, but only when, in the crustacean degree, frightened, or hurt. This action of the largest muscle of the crayfish is quite in line with a far-reaching theory that in general throughout the animal kingdom shocks and other disagreeable states usually are correlated

in the neuromuscular mechanism with contraction of those muscles classed as flexors.[1] The consideration, then, that so large a proportion of the individuals are uncertain in their habits of re-turning becomes still more conspicuous in view of the occasional commencement of a discrimination between voluntary and reflex control which these two empirical methods seem to imply. The only crayfish which alone invariably re-turned by abdominal flexion was the one that made the best record at gripping; this animal showed only average traction power and sensitivity. He continued to re-turn by flexion until apparently fatigue of the flexor abdominis ensued, when he adopted the balancing method, especially easy for him because one chela was smaller than the other. His obvious unusual voluntary control of his flexor muscle seems only another inconsistency in habit. Other subjects never flexed the abdomen for overturning purposes, but indefinitely struggled with legs and chelæ.

The various reactions which the constant electrical current caused the different crayfish in water to make, indicate apparently both a wide variation in the sensitivity of the various animals to this sort of stimulation and a large diversity and inconstancy in the neuromuscular apparatus or conditions, even when the external circumstances are invariable. Human beings display a like variation in sensitivity to electricity, but probably not a like diversity in their motor reactions to their sensations. No correlations apparently can be discovered between the results of this set of observations and those of the other sets. Those crayfish susceptible or insusceptible to galvanism are not in similar relations as regards galvanotropism nor hypnosis; not correspondingly quick or slow in the time of their reactions, nor weak or strong in their muscular strength. The writer has failed to discover anything in these results so far comparable to individual "temperaments" as "sensitive and weak" or "dull and strong." However useless a word this "temperament" is being proved to be, it does mean something in its psychophysical aspect of muscular strength and quickness. Even with this very limited application, evidence for its existence in crustaceans seems wholly lacking.

In the experiments on variations in galvanotropism there was an unanimity of what one may call perhaps by analogy anodotropism which is still imperfectly explained. Sensitivity to the electrical influence varied very greatly, some animals going to the anode in a

[1] See DEARBORN: The emotion of joy. Macmillan's, 1899, pp. 41 *et seq.*

second or two, as already suggested, others crawling thither along the edges of the vessel as if against their wills; some staying a long time under the cathode in the corner and others never; some going backwards by preference, slowly turning around into position for so doing, others walking deliberately forwards or sidewise. Here likewise correlations fail to appear and individual types or permanence are not at all discernible.

The sixth series of experiments described above, those on that condition which Verworn[1] thinks best to call "die sogennante Hypnose," gives us results far more suggestive than those just commented on in that the consequences are more pronounced. As in the other cases, these experiments were not carried out as a study of the phenomenon in question, but hypnosis was employed merely because it offered a convenient test of individual variations in a direction involving whatever of mind the lowly crayfish may properly be said to possess. However, not a little time was devoted by the writer to this interesting phenomenon in the crayfish, enough at least to show the correctness of the eminent physiologist's observations and at the same time to suggest objections to his refusal to correlate the condition with hypnosis in the human subject. These two, in short, appear to the writer to be the same process, when the necessary vast allowance is made for the difference in the psychophysical status of the man and that of the crustacean. As suggestion and still more as sensory impression (the two theories), hypnosis, broadly speaking, is but the placing of restrictions on a weaker organism by one which at the time and by means of this accepted influence is the stronger. In man this clearly is done usually by will as mind or body or both working on both of these as the will of the subject. In the crayfish, where mind is at a relative minimum, the muscles are the psychophysical side primarily impressed and the sensations, secondary, arising therefrom appear to react upon the muscles for a length of time varying largely in different cases and individuals. But this latter mode also is often applicable to human beings as well, as in certain conditions of catalepsy in which as here the muscles may be immediately controlled. Moreover, Professor J. Mark Baldwin has reported[2] how he restrained the reflex movements of his infant child and put her to sleep in a manner apparently quite similar to that employed in these manipulations of crayfish.

[1] VERWORN: Die sogennante Hypnose der Thiere. Jena, 1898.

[2] BALDWIN: "Mental development in the child and the race," 2d edn.; p. 116

In these simple experiments with hypnosis, almost more than in any others, inconstancy is supreme. It is not possible to class any of the eighteen individuals by a hard and fast criterion as either susceptible or not so. Easily and quickly hypnotized once, a crayfish often the very next trial required many times as long an impressing, and this notwithstanding an increasing susceptibility in general. Like statements apply to the duration of the hypnotic influence both in the individual and in different individuals, the variation here being found to be still more conspicuous.

The attempt to secure in case of the crayfish an individual reaction-time by the method so often employed in taking the reaction-times of human subjects, yielded results very suggestive in the direction of our general problem: on them we can, perhaps not improperly, lay much stress. The neuromuscular process in these reaction-time experiments seems to be more closely correlated with what may analogically be termed the crayfish mind than in any other of the foregoing sets of experiments. In the human subject, the quickness of the reaction seems due to the tension of the will force exerted at the moment, known as the expectant attention — a strain of waiting for the signal, the rest of the action being often subconsciously automatic. In the present case the process is somewhat different, there being here of course no precise expectation of the stimulus. Taking the place of this, however, there is a certain general excitement, directed only in a minor degree as an emotion of defence most like to anger, and which, as far as consequences are concerned, acts practically in the way anger acts in man. As respects the reaction itself, the psychophysical conditions would seem to be similar in the two animals. It would be no valid objection to our method here to say that such reactions of the crayfish are more properly reflex actions, for such do the movements of a man become practically after a few repetitions of the reaction-time process. The conditions of the experiments, especially the presence of the hard shell intervening between the stimulating or signal instrument and the muscle itself, prevented any possibility that the reaction represents a mere direct muscular excitability to stimulation. That the reaction-time of the crustaceans and even of the yet lower molluscs under certain circumstances is as short as that of the mammal, common observation shows: hermit crabs dart into their houses often with extreme quickness when frightened, and the writer remembers well the astonishing agility with which an octopus, come upon suddenly while

climbing over the rocks, was gone, — it was but a flash, and the stimulus was probably quite unexpected. It would be mere pedantry to venture to discriminate in kind these reflex reactions from those we have measured in the crayfish, yet an element of excitement or an emotion of anger was present in the crayfish while being irritated in experimentation which makes the crayfish reactions more representative of the psychophysical status of the animals. This is an element which serves as a sort of attention expectant of further stimuli, as already suggested. Thus there is here in a sense and degree a measure of the individual's "mental" and psychophysical grade.

The mean time of the reaction of the several individuals has already been given: in expressing this as a mean instead of as an average we of course have avoided the influence of extremes, yet the numbers arrived at are various enough and show a large range, namely between 0.20 and 0.65 second. Furthermore, it may be said that in several instances measurements were excluded as chance "reactions" or as possibly "anticipatory" which perhaps should have been included and others, two or three, because they seemed too long. Such a practice, quite admissible in computing human reaction-time (because the results of experience show the normal constancy of the periods), may be erroneous in dealing with animals low in the zöologic development, but to be conservative it was here employed. Were these extreme periods admitted, the range of reaction-time as studied in these experiments is for only ten crayfish rather more than a second, some of the doubtful times being approximately 0.10 second and others, although fewer perhaps, considerably over a second. But more striking even than this empirical large range among the individuals, are the individual mean variations, which are accordingly given here: —

II	0.25 sec.	VIII	0.025 sec.
IV	0.25 "	XI	0.80 "
V	0.25 "	XII	0.45 "
VI	0.35 "	XXI	0.385 "
VII	0.175 "	XXV	0.50 "

In six of these ten cases the mean variation is equal to or longer than the mean reaction-time, a fact which speaks for itself. Moreover, no correlations could be discovered between the reaction-time of an animal and his performances in the laboratory in other directions. One quick at one thing was slow or average or quick at

another apparently quite as it chanced at the moment. A slow animal does not appear to be strong or average or weak or sensitive or insensitive or clever or stupid save by "chance" combination of circumstances. These reaction-times, involving in their production as they do a psychical element larger than was involved in the other experiments, form a sort of climax to our demonstration the outcome of which, from the standard of theory, was already foreshadowed in the traction tests, most material and somatic of them all.

Conclusion.

The results of this tentative research being now considered in detail, only the inevitable general conclusions remain to be expressed. The *absence of correlations* and the *inconstancy* are the two significant features of the results. In a vague and purely physiological way both of these are undoubtedly present in the crustacean nature, as the numerical products of the various sets of experiments show. Such constancies and correlations are inevitable from the greater or less stability of the material "basis" of vital phenomena. It was evidence for the presence or absence in the crayfish of a less somatic sort of individuality that we sought. Of this practically nothing, save a mere evolving beginning, has been found in the crayfish. The only "individuality" of which in this particular animal evidence has been gained is a bodily individuality dependent in part rather strictly on unknown immediate internal conditions and mediately, in the long run, purely on environment.

Experiments more or less like these may in the future aid in defining the several grades of individuality in orders of animals progressively nearer to man.